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SOME HYDROGRAPH CHARACTERISTICS OF ARID-LAND WATERSHEDS

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Data presented in this report pertain to the mixed grass and brush rangeland of southern Arizona and the blue grama grasslands of east central New Mexico. Elevations vary from 4200 to 6000 feet on the Walnut Gulch, Arizona, Watershed, and 4500 to 5200 on the Alamogordo Creek, New Mexico, Watershed. Annual precipitation at Walnut Gulch is 12 to 15 inches, and 14 inches at Alamogordo Creek. From 50 to 75% of the annual precipitation and essentially all of the runoff occurs during the June to September period as a result of intense, small diameter convectional thundershowers.

Stream channels in the Walnut Gulch watersheds are typical of the semi-arid Southwest. The gradients are steep (1%) and consequently the flow velocities are high, and at higher stages approach critical velocity. The flow in these channels is highly ephemeral with most of the gaging sites having only 5 to 10 runoff events per year and no base flow. In a typical reach of channel, several feet of loose sand and gravel overlie bed rock. On the main stem of Walnut Gulch, the channel varies from about 25 to over 500 feet in width.

The Alamogordo Creek, New Mexico, Watershed has an unusual drainage system. The central and upper portion of the watershed consists of a broad flat valley floor surrounded by an escarpment. The main stem has an incised channel for only a small portion of the total length. Upstream progress of the head cutting has been arrested by rock outcrops. Above the incised reach, the channel widens out abruptly into broad swales. This poorly defined drainage system with the large valley storage has a very marked effect on the hydrograph as will be shown later.

In the Southwestern area of the United States where runoff data are scarce, the designer must resort to some method of estimating hydrograph characteristics from the physiographic features of the watershed. The method entails estimating (1) a time parameter based upon watershed characteristics; (2) using this time parameter to estimate the hydrograph peak from an assumed volume of runoff; and (3) synthesizing the entire hydrograph from this time parameter, hydrograph peak, and a standard dimensionless hydrograph.

In a recent paper by Hickok, Keppel, and Rafferty[2/], such an approach was used on small watersheds (up to 1000 acres) in the Southwest. Their findings can be summarized briefly by saying that the

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2/ "Hydrograph Synthesis from Small Arid-Land Watersheds." Hickok, Keppel, and Rafferty. Ag. Engr., Vol. 40, pp. 608-611, Oct. 1959

least variable and most readily determined time parameter was the time from the center of mass of a limited block of intense rainfall to the resulting peak of the hydrograph. They called this parameter the watershed lag time. The regression equation expressing lag time as a function of the source-area parameters was found to be:

$$T_L = 23 \left[\frac{\sqrt{L + W}}{S\sqrt{DD}} \right]^{0.65}$$

Where: T_L is the lag time in minutes

L is the length from the outlet to the center of the source area in feet

W is the average width of the source area in feet

S is the average slope of the source area in percent

DD is the drainage density of the watershed in feet per acre

For the thirteen watersheds considered in this study, the rise time was found to vary from 74 to 145 percent of the lag time with an overall average of 102 percent. They therefore constructed a dimensionless hydrograph with lag time and time to peak equal. This dimensionless graph and the one in the Hydrology Guide are so similar that they are considered one and the same in this report.

Time of concentration (time required for water to travel from the hydraulically most distant point to the watershed outlet) is very frequently used as the time parameter. On semi-arid watersheds larger than about two square miles, time of concentration is a difficult time parameter to use. The convectional thunderstorm cells which cause runoff are often two miles or less in diameter. On a watershed of several square miles in area, storms appear to occur in a more or less random pattern, as single or multiple-celled events. On a given watershed, each storm pattern would be characterized by a different time of concentration and for multiple-celled events, several different concentration times may be involved in a single runoff hydrograph. Similar objections may be raised to the use of lag time.

For the watersheds discussed herein, time to peak varies within rather narrow limits (see tabular data Figure 1). Lag time is subject to wide variations, particularly on the larger watersheds, since the point of occurrence of the storm center may be very close or very far removed from the watershed outlet. Comparison of the August 10, 1959, and August 20, 1960 storms will illustrate this point. The August 10, 1959 storm which occurred toward the upper end of the watershed had a lag time of 143 minutes and time to peak of 6 minutes. The lag time and time to peak for the event of August 20, 1960 were 30 and 29 minutes respectively.

Figure 2 shows average time to peak versus watershed area for the watersheds in southern Arizona. Average time to peak is derived from all the suitable hydrographs on the particular watershed under consideration. It can be seen from this graph that time to peak decreases with increasing area. This is contrary to what one would expect in other parts of the country. The regression equation is:

$$t_p = 29\ A^{-0.2}$$

Where: t_p is the time to peak of the hydrograph in minutes

A is the watershed drainage area in square miles

A possible explanation for this relationship is that runoff from the intense convectional storms move into the channel system in the form of abrupt translatory waves. These waves as they move down the channel tend to over-ride building into one abrupt wave near the front of the hydrograph thus accounting for the rapid rises. Obviously, this trend of decreasing time to peak with increasing drainage area cannot be expected to continue much beyond the limits of the data.

Another interesting comparison of time to peak was obtained by plotting it against the hydrograph peak (Figure 1). The data for the individual watersheds has such a wide scatter that there is no apparent consistent relationship between the two. As previously explained, time to peak appears to be controlled by the over-riding waves in the channel systems. Therefore, on a particular watershed, the further from the outlet the runoff started, the shorter the time to peak. It is also believed that abstraction of flow from the rising limb of the hydrograph due to transmission losses also tend to accentuate this over-riding effect.

Figures 3 and 4 show the average dimensionless hydrographs for the Walnut Gulch, Arizona and Alamogordo Creek, New Mexico watersheds. In addition, the dimensionless graph from the Hydrology Guide is shown for comparative purposes. The average graph was made using all suitable runoff hydrographs and was made dimensionless in terms of time to peak.

Several interesting observations can be made from these graphs. For the Walnut Gulch watersheds, the recessions of the dimensionless graphs are more extended with increasing watershed area. This is because time to peak decreases with increasing area, and consequently when plotted in dimensionless form, the recessions are displaced to the right. This displacement increases with decreasing time to peak, and consequently with increasing area.

The Alamogordo Creek dimensionless hydrographs in Figure 4 require special explanation. The flat top (i.e. $q/q_p = 1.0$ for a number of different t/t_p ratios) hydrograph as previously mentioned

appears to result from flows orginating in the central and upper portions of the watershed where the broad shallow swales of this poorly defined drainage cause a great deal of valley storage. The lower tributaries, however, have incised channels for a greater percentage of the channel length and therefore have the more typical peaked dimensionless hydrograph. Another interesting observation is that the flat top in all the hydrographs considered lasted very nearly two hours but that these peaks occurred at widely varying discharges. The longest time at the peak was 162 minutes and the lowest 110 minutes, with an average of 132 minutes.

TABLE I

Watershed	Drainage Area Sq. Miles	Average Time to Peak Minutes	Peak Discharge Range High (cfs)	Low
Walnut Gulch				
# 1	57.65	11	20,000	910
# 2	43.92	19	3,675	860
# 3	3.47	17	2,830	710
# 4	0.875	21	1,425	337
# 5	8.60	24	5,300	460
Alamogordo Creek				
Main Stem	67.0	25	7,400	1,085
Southeast Branch	10.0	33	2,683	1,660

Because of the highly ephemeral nature of these streams (channel is dry as much as 99% of the time) the recession curve should reflect only direct runoff being discharged from channel storage. The recession curve of direct runoff can be treated in the same manner and under the same assumptions as the ground water depletion curves. The assumptions are that (1) no inflow to channel storage is occurring and (2) that no outflow from channel storage is occurring except the stream discharge at the point under consideration. Because of transmission losses, this second assumption cannot be rigorously true. However, the channel system for the most part is believed to be underlain by a relatively impervious conglomerate that probably allows only a slow downward movement of the water. Therefore, the majority of the transmission loss can be assumed to come from the rising limb of the hydrograph when the voids in the channel alluvium are filled. Thereafter, only a small constant extraction occurs on the recession.

With these assumptions in mind, the recessions for the dimensionless as well as the natural hydrographs were plotted on semi-log paper for all the watersheds. The only trend that appeared to exist was that the

constant (K) in the recession equation

$$q_t = q_o K^t$$

Where q_o = discharge at a specific time

q_t = discharge at an elapsed time of t units

t = the number of time units between the discharges

K = a constant with a value less than one that indicates the channel depletion characteristics

appears to vary with antecedent runoff. The lower portions of the recessions appear steeper following dry periods and have the typical break (where the straight line recession starts) at a higher discharge than following a moist period. The outcome of this recession work is that the assumptions made concerning transmission losses on the recession side of a hydrograph probably apply only for the extremely high peak discharges such as the flow of August 17, 1957 when the outflow from Watershed 1 on Walnut Gulch was 20,000 cfs peak.

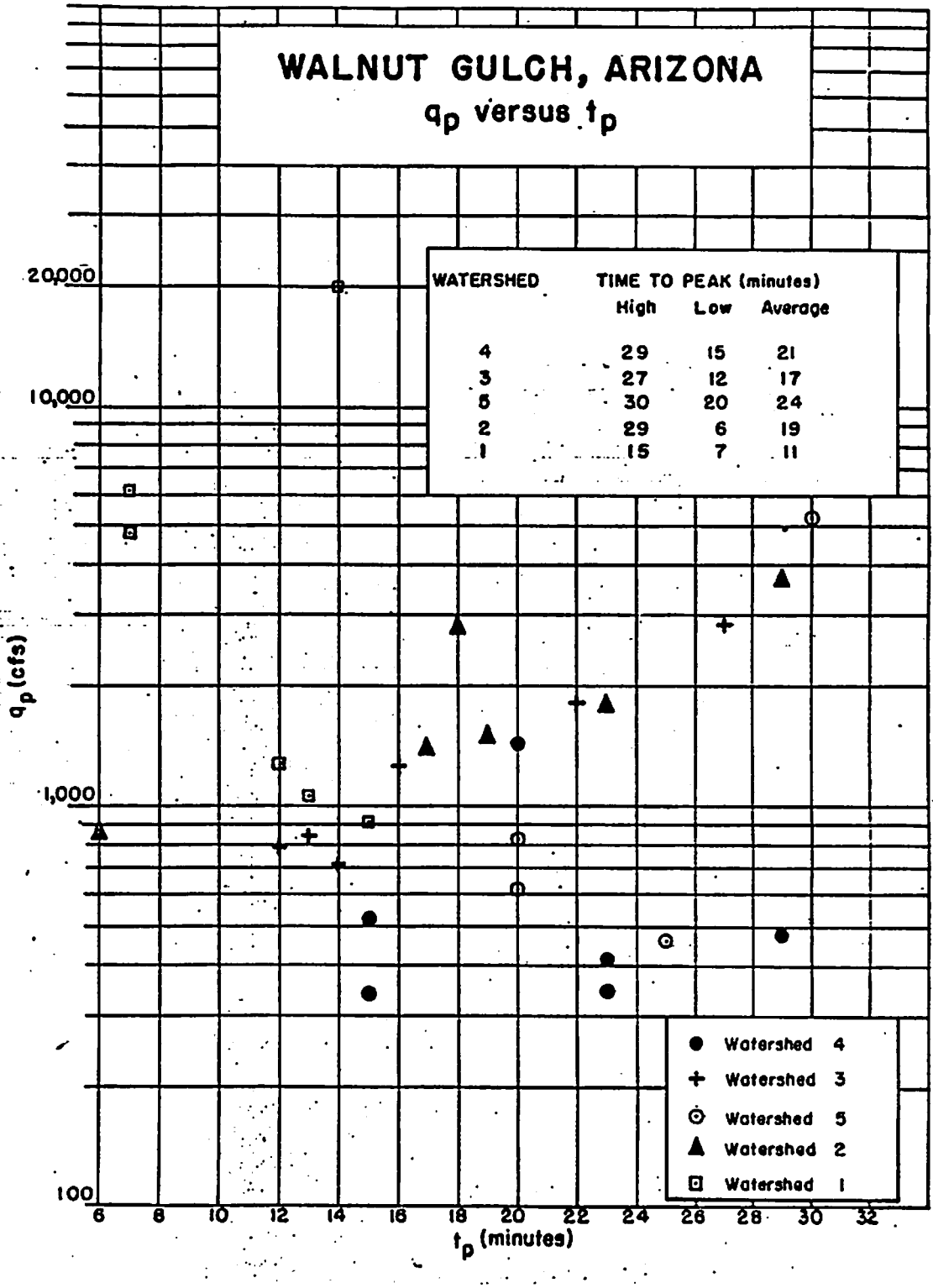
Conclusions. For the watersheds used in this study, time to peak was found to be the only time parameter that seemed feasible to use in defining watershed influences on hydrograph shape. Because of the random fashion in which the thunderstorm cells occur, a different lag time or time of concentration would be needed for each runoff event.

One might expect time to peak to be a function of the peak discharge, however, Figure 1 shows very little correlation between the two. The distance that the water has traveled in the channel system is thought to have the greatest effect on time to peak because of the over-riding translatory waves. At present, there are insufficient data to quantitatively evaluate these reductions. A fair indication of this is offered by noting that time to peak (average) decreases with increasing drainage area in the Walnut Gulch Experimental Watershed. Obviously, this relationship cannot continue far beyond the limits of this size watershed.

Because of the decreasing time to peak with increasing area in the Walnut Gulch watersheds, the average dimensionless graphs become correspondingly magnified on the recession side with increasing area and therefore, show a wide variation from the average dimensionless graph presented in the Hydrology Guide.

As more runoff data become available, it seems quite certain that flood routing will be the most accurate method for predicting the hydrograph at some point downstream from the source of the initial runoff. The method of Hickok and Keppel could be used to synthesize the hydrograph from the small unit source areas. Using travel times in the channel as well as transmission loss data, the hydrograph could then be constructed at the downstream point in question.

Figure 1


WALNUT GULCH, ARIZONA
q_p versus t_p
WATERSHED
TIME TO PEAK (minutes)
High Low Average
4 29 15 21
3 27 12 17
5 30 20 24
2 29 6 19
1 15 7 11
20,000
10,000
1,000
100
q_p (cfs)
6 8 10 12 14 16 18 20 22 24 26 28 30 32
t_p (minutes)
Watershed 4
Watershed 3
Watershed 5
Watershed 2
Watershed 1

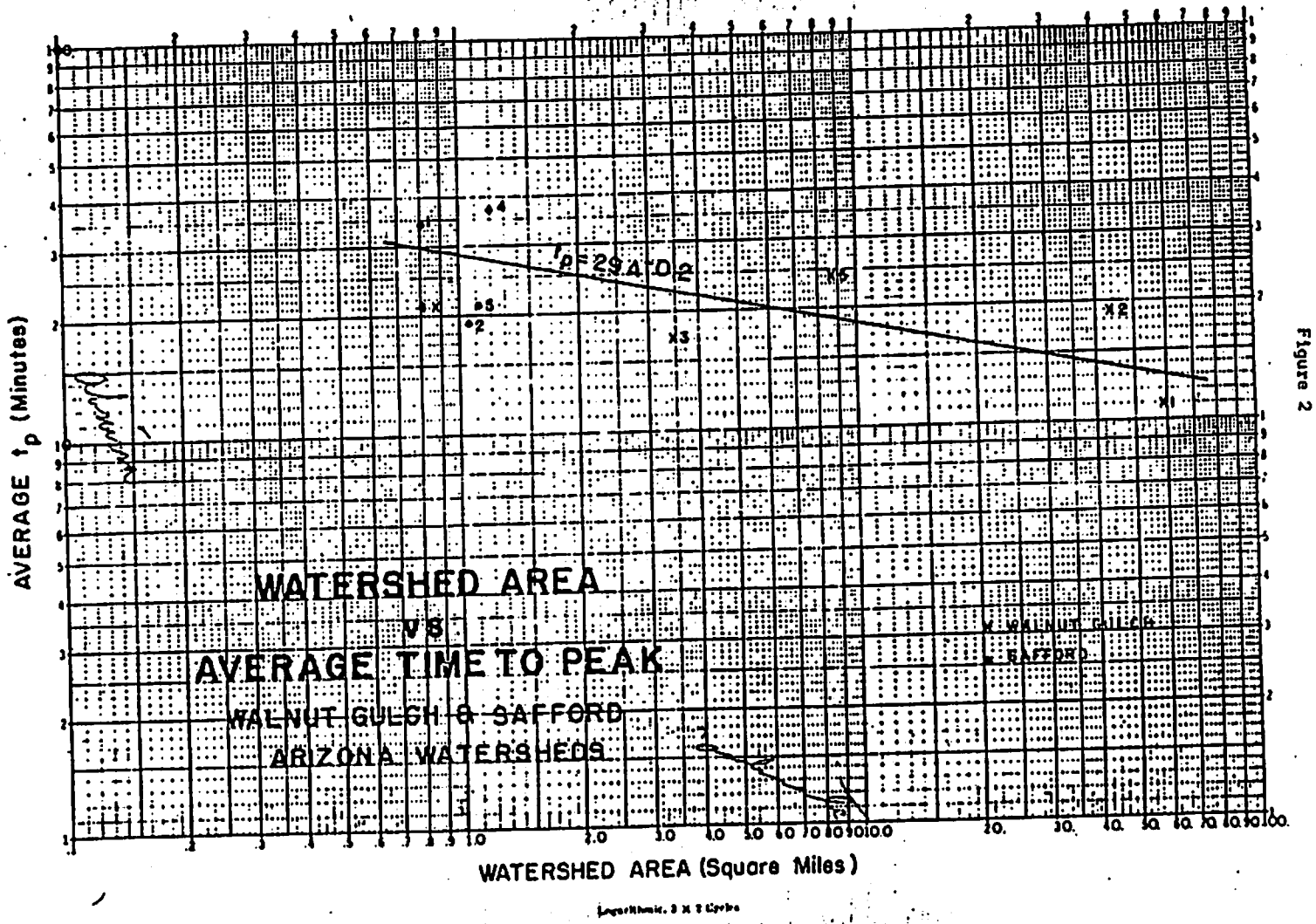
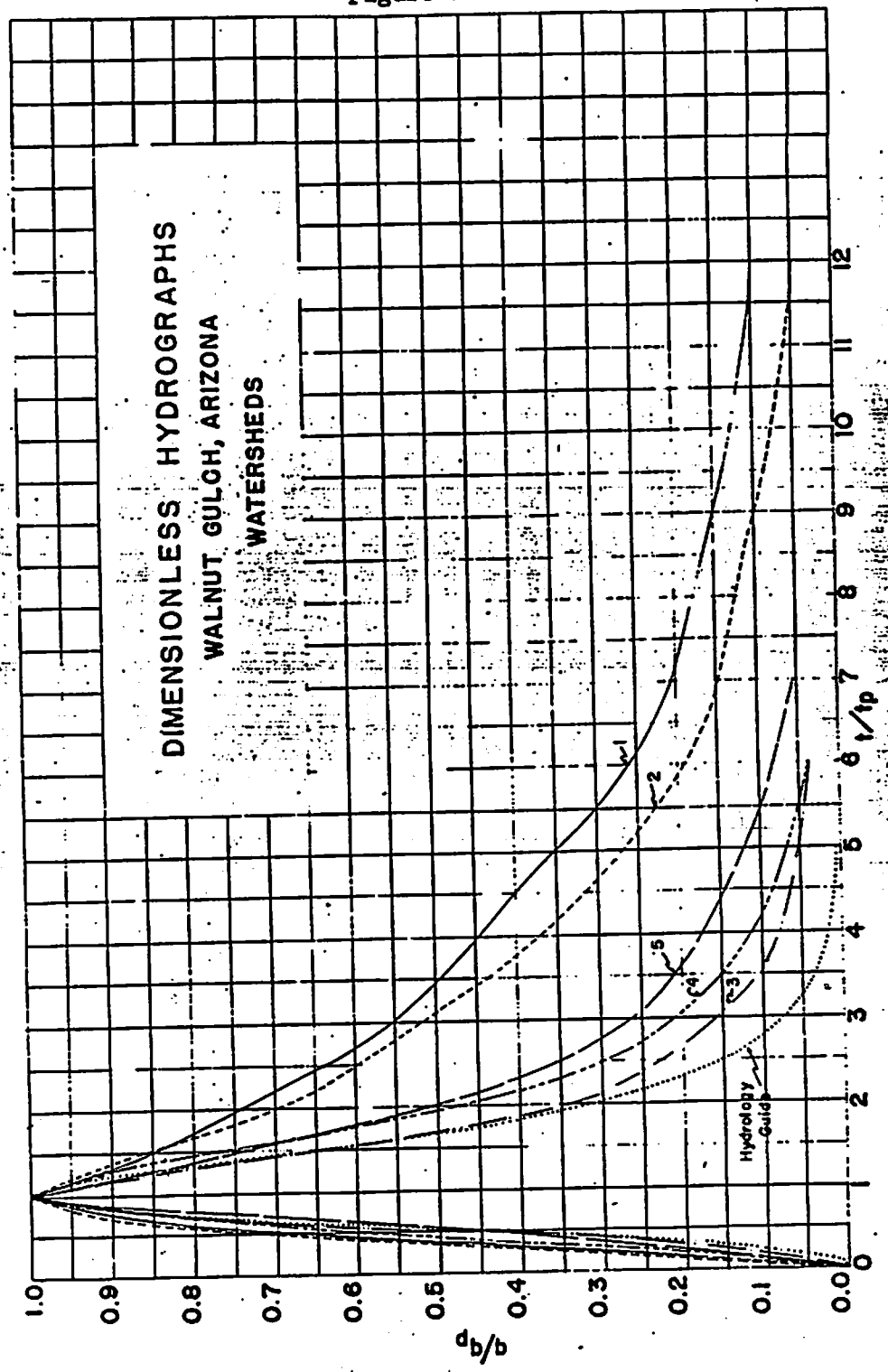

WATERSHED AREA
VS
AVERAGE TIME TO PEAK
WALNUT GULCH & SAFFORD
ARIZONA WATERSHEDS
$t_p = 29.4 D^{.2}$
X WALNUT GULCH
SAFFORD
AVERAGE t_p (Minutes)
WATERSHED AREA (Square Miles)

Figure 2

Figure 3


DIMENSIONLESS HYDROGRAPHS
WALNUT GULCH, ARIZONA
WATERSHEDS
1
2
3
4
5
Hydrology Guide
q_b/q_p
t/t_p
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12

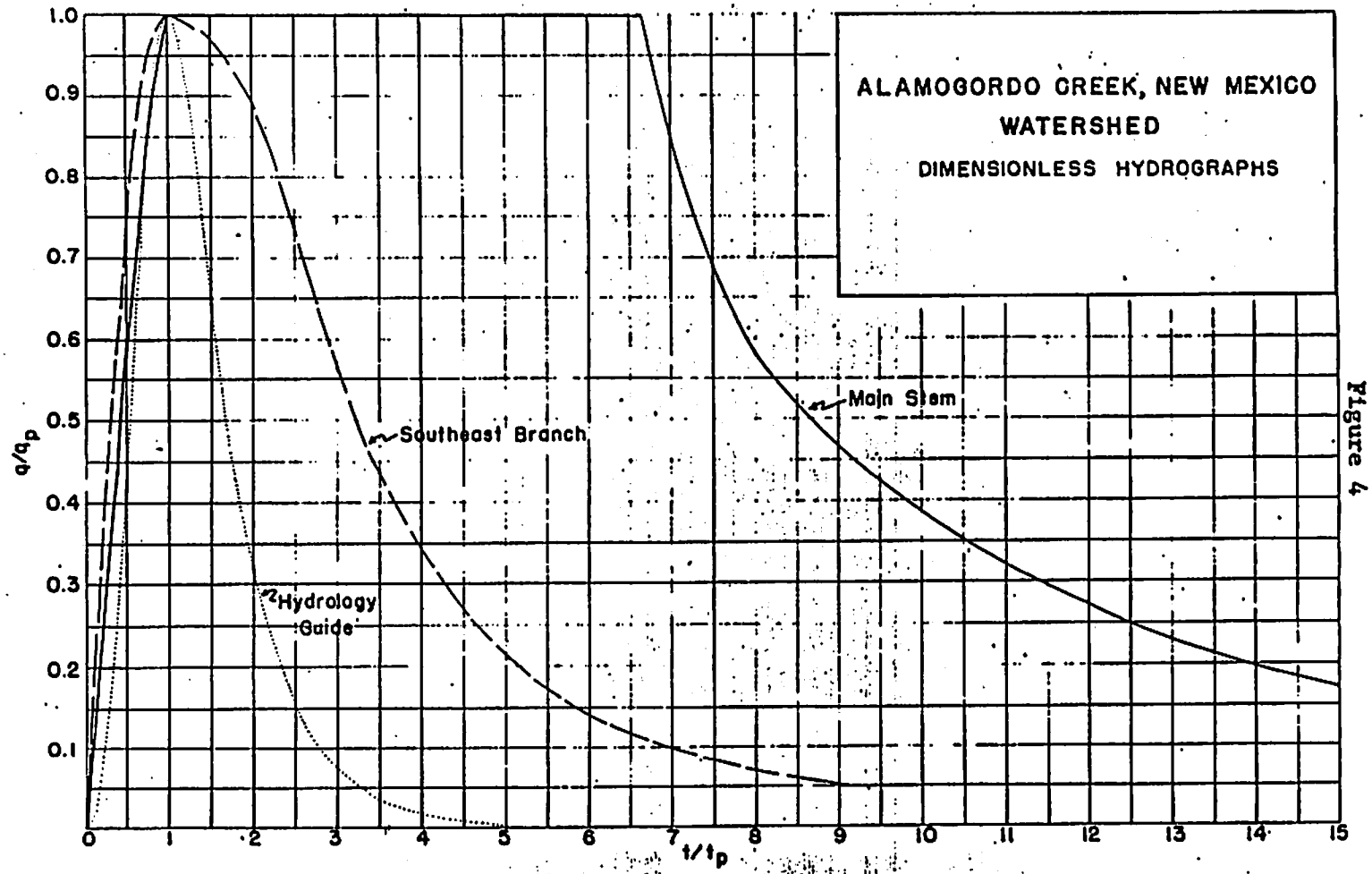

ALAMOGORDO CREEK, NEW MEXICO
WATERSHED
DIMENSIONLESS HYDROGRAPHS
Main Stem
Southeast Branch
Hydrology Guide
q/qp
t/tp
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Figure 4